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Safety First: In the Hyperbaric Environment

October 01, 2008
Volume 2 Issue 4 - Fall 2008 (/fall-2008-0)
Paul J. Sheffield, PhD, CAsP, CHT; Robert B. Sheffield, BA, CHT

The rapid growth in hyperbaric medicine facilites in the United States and throughout the world has created a demand for large numbers of new employees, some of whom have no experience and little training. This has heightened the concern for patient safety.

Each individual who works at the hyperbaric facility must know the potential for mishaps and use that information to safely operate the chamber and its support equipment. Although the hyperbaric medicine community enjoys an enviable safety record, it is important to periodically review hyperbaric mishaps and consider the lessons learned from prior

experience so we can avoid repeating them. There are five basic safety issues addressed herein: integrity of the pressure vessel, safe gas handling practices, decompression safety, fire safety, and staff training.

Integrity of the Pressure Vessel

Clinical hyperbaric chambers and systems used for patient care in the US must be constructed in accordance with the American Society of Mechanical Engineers (ASME) Standards for Pressure Vessels the [Boiler and Pressure Vessel Code (BPVC) and Pressure Vessels for Human Occupancy (PVHO)] or an international equivalent. Chambers constructed to ASME standards are safe provided the operators are trained and are safety conscious.

In Wisconsin (1971) an acrylic monoplace chamber door failed at the bolt holes causing an explosive decompression from 3 ATA that caused the patient to experience bilateral lung collapse. Flying debris broke the jaw of the attending physician. Both patient and physician were medically managed and recovered. This mishap resulted in the formulation of specific rules for bolt holes in acrylics. Disregarding these rules, in California (1997) a hyperbaric chamber steel door was replaced with a locally fabricated laminated acrylic door so the physician could observe the patients through the door. The door failed at the bolt holes causing explosive decompression from 2 ATA resulting in the chamber being propelled backward into the wall. Two patients inside the chamber were not injured, but flying debris injured a nearby nurse. In South Africa (2004) a homemade hyperbaric chamber exploded as a result of a fire inside the chamber. The explosion caused severe property damage and took the life of a person outside the chamber in addition to the patient inside.

The lessons learned are:

a) Hyperbaric chambers must be constructed in accordance with ASME or equivalent standards; and

b) Qualified individuals in accordance with ASME or equivalent standards will perform any modifications to the chamber.

Safe Gas Handling Practices

The two areas of concern are a gas mix-up that results in the patient receiving the wrong gas and mishandling that causes damage to the gas cylinder.

There are a number of examples of wrong gas being given to patients in hospitals and nursing homes with fatal consequences. One example involved an Idaho hospital (1998) gas mix-up in which two patients were killed when an industrial grade nitrogen cylinder was connected to the oxygen system. Another occurred in an Ohio nursing home (2000) where

three residents were killed and three others critically injured after a gas mix-up where an oxygen cylinder containing nitrogen was connected to the patients' oxygen system. It contained a nitrogen label, but the label was apparently not checked before installing the cylinder into the system. A Texas clinical hyperbaric facility (1980) experienced a wrong gas situation when liquid nitrogen was delivered to the liquid oxygen (LOX) tank. Fortunately, the multiplace hyperbaric facility had an oxygen analyzer system to check the breathing gas before it entered the chamber, so the error was identified and the gas from the LOX tank was shut off before it could cause injury to the seven patients inside the chamber.

Damage to the gas cylinder can occur if it is overheated, dropped, or rusts. Heat causes an increase in pressure inside the cylinder that can cause the cylinder to explode. That is why the fire department will want to know where all of the oxygen cylinders are in service or stored within the facility. When a cylinder is dropped and the regulator or fill port is broken, the cylinder will suddenly release its contents and become a projectile destroying anything in its path. In Colorado (2005) an airline mechanic was killed instantly when a large high-pressure cylinder (fire extinguisher) he was working on shot off at a high rate of speed, striking and killing the mechanic on impact. Pressure in the fire extinguisher was apparently too high so the mechanic was trying to release some of the pressure.

Gas cylinders are periodically inspected and hydrostatically tested by the gas delivery service, and a date stamp of the original hydrostatic test is etched in the top of the cylinder. Labels will show subsequent tests, which are conducted at five-year intervals. In Canada (2000) a dive shop was destroyed and the owner killed when a high-pressure air storage tank exploded. It had not been inspected for several years, and it had rusted sufficiently to fail while pressurized to 3000 psi (about 200 bar). The mishap was repeated in Grand Cayman, BWI (one fatality) and Florida (no fatalities).

The following lessons learned are:

a) Check the gas labels before installing a new cylinder into the breathing gas system.

b) Have a mechanism in place to analyze the breathing gas to ensure that it is pure oxygen.

c) Know and follow the rules for gas cylinder storage and inspection.

d) Chain or secure pressurized cylinders so they cannot fall over.

e)Check the hydrostatic test date stamp on the gas cylinders that are delivered to the facility to ensure that they were tested within the past five years.

Decompression Safety

Every member of the hyperbaric staff must know how to properly decompress the patient and attendant, if applicable. The staff at monoplace chamber facilities that pressurize the chamber with pure oxygen must also know the proper decompression procedure for air in the event that wrong gas is given to the patient. In Florida (1991) an inadequate decompression of the nurse inside attendant resulted in fatal injury from decompression sickness. The patient and attendant had completed a 6 ATA excursion on US Navy Treatment Table 6A (USN TT6A). At some point in the treatment at the 2.8 ATA level, it was discovered that the patient was receiving wrong gas, so the treatment table was extended to give the patient a proper treatment with oxygen. The nurse exposure time was also extended but, unfortunately, she was not given extra oxygen breathing to compensate for the longer exposure. In California (1999) an inadequate decompression resulted in decompression sickness and subsequent partial quadriplegia in the nurse inside attendant. The patient and nurse attendant had completed the 6 ATA excursion of USN TT6A. At the 2.8 ATA level the nurse told the chamber operator that she was ready to come out so she was brought directly to the surface, missing about 155 min of decompression obligation. At the surface she felt weak and collapsed. A course of hyperbaric oxygen therapy did not resolve her paralysis.

The following lessons learned are:

a) Training is mandatory on chamber equipment and decompression procedures.

b) Safe decompression procedures must be understood and followed.

Fire Safety

Sheffield & Desautels (1997) provided a 73-year analysis (1923–1996) of 77 human fatalities occurring in 39 hyperbaric and hypobaric fires reported in Asia, Europe, and North America. Sheffield (1999) updated the analysis with 20 previously unreported fires in Workman's textbook, Hyperbaric Facility Safety: A Practical Guide. The 59 chamber fires occurred during a 77 year period (1923–2000) resulted in 117 deaths worldwide. The report includes two fires (four deaths) occurred in diving bells, 20 fires (26 deaths) occurred in recompression chambers, and 32 fires (81 deaths) occurred in clinical hyperbaric chambers. Additionally, three fatalities occurred in a pressurized Apollo Command Module, and three fatalities occurred in five hypobaric (altitude) chamber fires.

Since the Workman textbook was published, there have been reports of four additional clinical chamber fires with five fatalities:

1) 2001 Chinese multiplace chamber fire caused by short in air conditioner; one fatality

2) 2002 Chinese monoplace chamber fire caused by cell phone; one fatality

3) 2004 South African homemade monoplace chamber fire and explosion, cause unreported; two fatalities (patient inside, operator outside)

4) 2006 Peruvian monoplace chamber fire caused by intercom; one fatality

Fires have occurred in both oxygen and air filled chambers and the ignition source is largest problem. Ignition sources included: Electrical shorts (nine), Static (seven), Smoking (six), Hand warmers (five), Toys (three), External Sources (two), Cell phone (one), and Unknown (three). Prior to 1980, electrical components caused 41% (24 of 59) of chamber fires and 55% (63 of 117) fatalities. Since 1980, chamber fires have been primarily caused by prohibited sources of ignition that an occupant carried inside the chamber. Chamber fires occurring in the last 15 years illustrate the need to control ignition sources from chamber access.

1) Hand warmers (two events). In Japan (1996) a chemical hand warmer caused a fire that killed the occupant, and the resultant chamber explosion killed his spouse. In Italy (1997) a hand warmer filled with benzene caused 11 fatalities.

2) Cigarette lighters (two events). In Belgium (1993) and United Kingdom (1996) cigarette lighters or smoking by inside occupants resulted in two fatalities.

3) Toy (one event). In Cuba (1997) a child's friction toy caused a fatal fire within minutes before the treatment was to conclude.

4) Cell phone (one event). In China (2002) a patient's cell phone ignited the chamber interior resulting in fatal burns.

5) Unreported object (one event). In South Africa (2004) an unreported object caused a fire with two fatalities.

Because wound care professionals place emphasis on chamber fire prevention, the hyperbaric medicine community has a remarkable fire safety record. As of this writing, 36 clinical chamber fires have resulted in 86 worldwide fatalities over the past 85 years (1923–2008). The incidence of hyperbaric fires is so small that the US Fire Administration (USFA), an entity of the Department of Homeland Security's Federal Emergency Management Agency, does not include them in their statistics. By comparison, USFA estimates that during 2007 there are 1.6 million fires in the US, resulting in 3,430 civilian deaths and 17,675 civilian injuries.

Lessons learned

1) **Patients/Staff.** Most of the recent clinical hyperbaric chamber fires have been started by the chamber occupants (staff or patients who smoked; patients who were cold; patients with cell phones; and children with toys).

2) **Survivors.** The only survivors were in chambers pressurized with air in which oxygen

percentage was known to be below 24%. There were survivors in one clinical hyperbaric chamber fire in which the outside operator extinguished the fire by water deluge fire extinguishing system (FES). There were also survivors in two diving decompression chamber fires in which the outside operator brought the chamber to surface and extinguished the fire with water.

3) **Igniters.** Special vigilance is required to ensure that no igniters enter the chamber.

4) **Oxygen.** Oxygen percentage in multiplace chambers should be kept below 23.5%. There have been no survivors of chamber fires that had oxygen above 24%.

5) **Burnable material.** The amount of burnable material must be limited. Paper products should be stored in metal containers when not in use

6) **Extinguishment.** Water deluge FES and hand aimed hose are effective in putting out a fire.

7) **Signage.** Signs should be posted in the vicinity of the chamber and clothing change stations to remind patients of the forbidden items.

8) **Checklist.** Checklists should be used for daily operations. Patients should be briefed about items that are excluded from the chamber, and reminded prior to each treatment.

Staff Training

The staff must be trained, present, and vigilant in order to avoid mishaps. Each member of the staff should attend formal training. Physicians should attend a UHMS Designated Introductory Course in Hyperbaric Medicine of at least 40 academic hours. Nurses and technologists should attend a NBDHMT approved introductory course of at least 40 academic hours. Each member of the staff should also be encouraged to achieve board certification in hyperbaric medicine. Each hyperbaric facility should appoint a Hyperbaric Safety Director and send that individual for special safety training. A list of UHMS jointly sponsored Hyperbaric Medicine Introductory Courses and Hyperbaric Safety courses can be found at the UHMS website, www.uhms.org, under "Courses and Exams." A list of NBDHMT approved Hyperbaric Medicine Introductory Courses can be found at www.nbdhmt.org.

Conclusion

Lessons learned from previous mishaps have resulted in improved guidelines for safe chamber operations. The hyperbaric facility is safe–provided a qualified team with a safety conscious attitude who adhere to establish safety practices operates it. *Paul J. Sheffield, PhD, CAsP, CHT, is President, International ATMO, Inc located in San Antonio, Texas. Robert B. Sheffield, BA, CHT, is Director of Education, International ATMO, Inc.*

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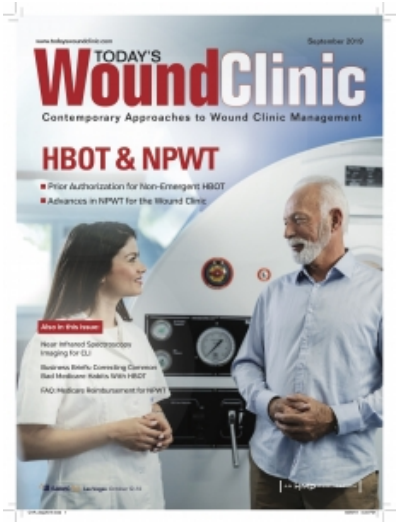

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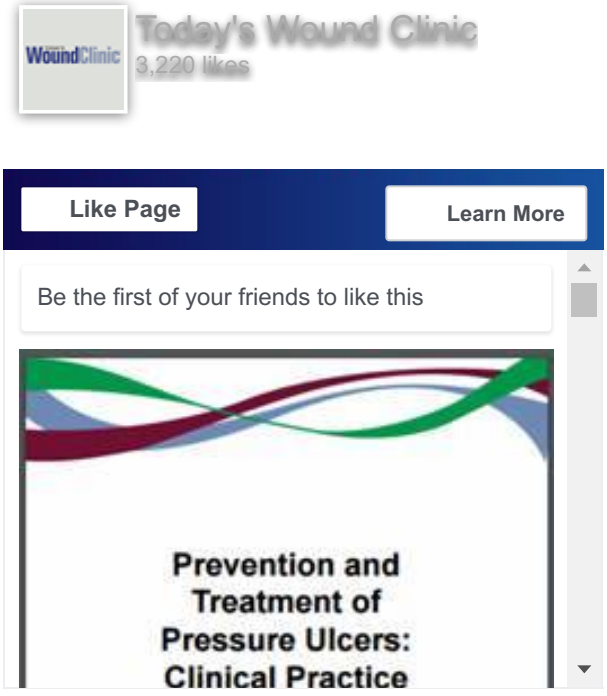

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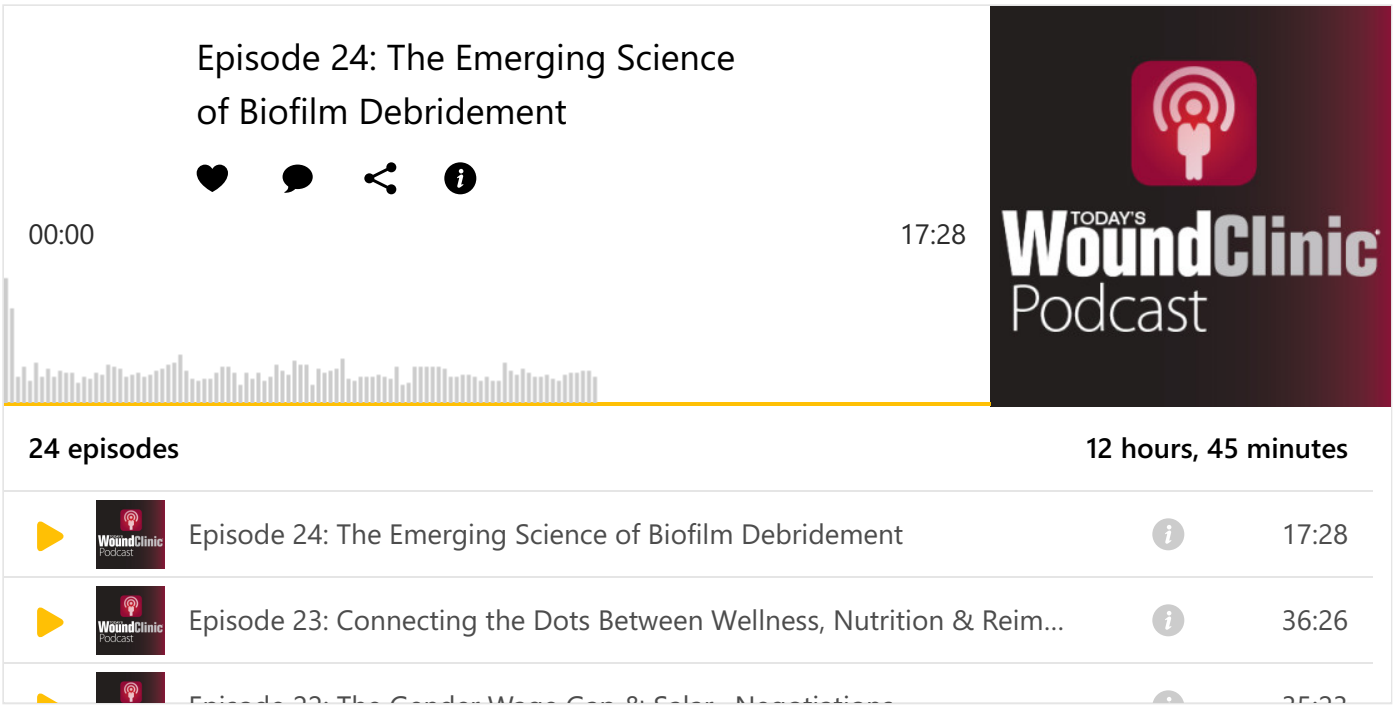

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